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Planetary Protection Issues in the Human Exploration of Mars

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ABSTRACT

A recent NASA workshop examined systems and concepts that might enable the future safe and productive human exploration of Mars. The workshop emphasized planetary protection (PP)issues—protecting Mars from forward contamination during exploration, protecting astronaut health during the mission, and protecting Earth from back contamination upon return. A range of critical design and operational considerations were identified including mitigation procedures and equipment; human health and life support needs; mission tasks and schedules; equipment and operations for laboratory, habitat, life support,exploration, sampling and sample integrity needs, and sample; and back contamination controls and procedures for the return to Earth. The workshop report includes findings and recommendations that are likely to affect the design and cost of advanced life support systems for long duration human missions to Mars.

INTRODUCTION

Although long-duration human interplanetary missions to the planets are not planned for the near future, discussions are already underway about the implications of human exploration of Mars. A primary consideration is whether human missions can be accomplished in ways that avoid harmful cross contamination of planets as required by the Outer Space Treaty of 1967. Based on policies and concerns about planetary protection (PP), space missions must be careful of what they bring along with them, what human or robotic explorers are exposed to in strange new worlds, and perhaps, especially what could be brought back to Earth and how it will be handled. NASA recently completed a series of international workshops that developed a Draft Protocol for handling and testing martian samples returned to Earth by future robotic missions (Rummel et al. 2002). The Protocol includes a comprehensive list of physical/chemical tests, life detection analyses and biohazard assays, as well as guidelines for containment, cleanliness, sterilization, facilities and equipment that will be used upon sample return. The latter areas will require extensive input from engineering and technical communities well in advance of launch (Race and Rummel 2003 ICES). As part of planning for future human exploration of Mars, it will likewise be important to focus on PP concerns well in advance of missions.

Two previous studies by the National Research Council (NRC) focused on human issues associated with exploration for evidence of life on Mars. In a study on biological contamination of Mars, the National Research Council recommended that human missions to Mars not be attempted until robotic missions can address the question of life on Mars (NRC, 1992). Since that time, considerable new knowledge has been generated about the Red Planet through both robotic one-way missions and other research (e.g., martian meteorite research and studies of terrestrial analogues), although the question of whether life exists there still remains unanswered. More recently, another study (NRC 2002) focused on the various precursor scientific measurements that will be needed to support human operations on the martian surface. Before human missions are planned, it will also be important to analyze whether and how human exploration can be accomplished in the face of current PP requirements. Obviously, the introduction into future exploration activities of human astronauts, with all their needs and abilities, greatly expands the mission scope and the PP issues from those of robotic sampling and other precursor mission. Prior to any human missions, it will be essential to understand the opportunities and risks involved; to eliminate, mitigate or minimize risks wherever possible; to plan mission activities in a way that avoid unnecessary exposures; and to develop mission plans that are both prudent and permissive of human activities while providing robust operating procedures that are tolerant of potential human errors and the unknown.

In order to address these concerns, NASA organized a 2-day workshop in June 2001 to specifically examine the planetary protection implications of human presence and exploration on Mars (Criswell et al., 2003). A primary reason for a martian mission to include humans is the expectation that humans will be better able to explore, identify and examine scientifically interesting environments on Mars than may be accessible by even advanced robotic exploration. It is recognized that human missions to Mars will entail all the issues already examined for robotic missions, while being further complicated through the direct involvement of people and their accompanying microbial companions. The realities of orbital mechanics dictate that human missions to Mars must remain on the planet's surface for an extended period of time (many months). This means that the human life processes of nutrition, respiration, and digestive wastes will be quite challenging in addition to the requirements for habitat, life support, surface locomotion and exploration, all of which must be accomplished within closed systems. In the face of all these requirements, the primary question of the workshop was to examine whether human exploration can be done effectively without harmful forward or back contamination.

At the workshop, 29 invited participants examined key human and project needs and critical mission operations that could raise planetary protection concerns, along with strategies to mitigate or negate these concerns. In considering human missions, it is necessary to contemplate the idea of multiple 'ecologies' in the form of the martian ecology, human ecology, and the possible interaction of Earth and Martian resources and ecologies. Thus, the initial working title of the workshop was "When Ecologies Collide? Planetary Protection Issues in the Human Exploration of Mars?" – with the question mark deliberately indicating the uncertainty about Mars as an abode for life. Because we may still be uncertain about the existence or extent of life on Mars when early human missions take place, it is likely that both astronauts and robotic devices will both be important elements in exploring the planet together. Both will require planetary protection controls and considerations of different types. In a combined human-robotic scenario, exploration and collection of martian samples must be done in a way that avoids cross contamination at all times, from sampling through evaluation on site, and after sample return. Likewise, the astronauts themselves must be kept safe and healthy during their time on the planet and in space. With these requirements in mind, deliberations at the workshop were organized around three general foci: 1) protecting Mars from forward contamination during exploration, 2) protecting astronaut health throughout the mission, and 3) protecting Earth from back contamination upon return. The workshop was designed to take an engineering perspective on systems and concepts that might enable safe and productive human exploration of remote, hostile environments. Discussions examined a variety of design and operational considerations, using both Earth analogues (e.g., Antarctic and extreme environments) and space experiences (Apollo, Shuttle, Internationl Space Station, etc.) as models and backdrops for deliberation. Discussions also assumed the need to protect samples from contamination at all times. This paper provides an overview of the workshop and a discussion of the findings and recommendations that may directly or indirectly affect the design and cost of advanced life support systems for long-duration human missions to Mars.

WORKSHOP ORGANIZATION

The objective of the workshop was to produce utilization-oriented information on planetary protection issues, policies, and systems operations by encouraging the synergistic interchange among participants from within NASA and the broader scientific and engineering communities. The complex mixture of human presence, scientific objectives, equipment, exploration activities and space hardware was considered by first providing an overview of current human capabilities and plans in the context of scientific exploration of Mars. Tutorial topics at the workshop covered subjects such as PP issues, Exobiology and Mars science and exploration, robotics, extremophile research (cave, Arctic and Antarctic experiences), and human physiology in extended space missions.

Information presented at the workshop also included critical issues in support of the effective scientific study of Mars by humans including

- The information to be gathered by precursor robotic exploration
- The general nature of forward contamination mitigation efforts and systems
- The inevitable human health and back contamination questions associated with humans living and working for several to many months on Mars, even though within a local (base or mobile) supportive environment
- The return of these humans and at least parts of their life support systems to Earth
- The need for samples from the Mars environment to be free at all times from Earth contaminants so that information and conclusions from these samples can be scientifically valid and accurate.
- The uncertainties of human Mars mission design, available technologies at the time of a mission, precise mission tasks, landing site risks vs. local scientific opportunities, methods and distances of surface locomotion, and the overriding issues of "is there life on Mars? If so, where is it and what is it like? and Is it or other aspects of the Martian environment dangerous to the astronauts and to Earth?".

After the overview presentations and preliminary discussions, participants were divided into three work groups which formed the main foci for the workshop:

1) protecting Mars and Mars sampling from forward contamination-- i.e., "Protecting Mars and Science", which focused on mitigation procedures and equipment for both precursor robotic and human missions;

2) protecting astronauts against risks from the Mars environment—i.e. “Protecting Astronaut Health”, which considered hazards and consequence to human health from anticipated and unanticipated risks, control of exposure to risks during habitat occupancy and exploration operations; and

3) preventing back contamination of Earth from possible Mars contaminant sources—i.e., “Protecting Earth,” which addressed the linkages between sampling, handling and return preparations on Mars as well as inflight procedures and operations upon return to Earth.

Later in the workshop, participants were re-assigned to two additional subgroups with the specific tasks of analyzing operations that would enable a safe, productive human presence in the exploration of Mars. These “Operations” subgroups were instructed to examine six scenarios with regard to planetary protection: (1) distant surface sample collection, (2) sample analysis, (3) *in situ* resource utilization (ISRU) at a martian base, (4) plant growth experiments and greenhouses for supplying food, (5) sub-surface sampling (to 10m and to 1 km depth), and (6) what to do if and when life is found. In their deliberations they considered likely mission characteristics and objectives, mission tasks and schedules, habitat design, support and exploration equipment, and operating procedures consistent with forward and back contamination control and human health factors.

The first human mission to Mars will face a significant level of risk—it will involve a high degree of venturing into the unknown using a complex transportation and life support system with many advanced and state-of-the-art features. The mission faces long transportation times with periods of dynamic flight conditions and demanding flight navigation controls. Regardless of the development effort and the amount of component and prototype testing, the first human mission will be the initial experience of fully operating the complete system for its intended purpose. Many of the same overall mission risk factors affect both mission/crew safety and PP issues, in particular risk factors involving contamination issues. Crew safety, integrity of planetary protection and mission success thus are closely related overall goals.

The tasks of the workshop were to consider and analyze these interconnected requirements and risks, but not to specifically determine appropriate or acceptable targeted risk levels or attempt quantitative assessments of the risks. Rather, discussions reflected a general awareness and acknowledgement that at this early stage of planning, the workshop could help identify major risk factors, work toward better understanding of them, perhaps estimate the general scale of risks involved, and identify some steps to control, mitigate or eliminate risks through appropriate mission designs and operations. The workshop could also contribute by suggesting topics for future R&D and subsequent workshop foci. The workshop findings and general recommendations are briefly summarized below:

WORKSHOP CONCLUSIONS AND GENERAL RECOMMENDATIONS

A summary of the Workshop observations includes a mix of conclusions and recommendations, including:

1. Humans in a future Mars mission will have unique capabilities in recognizing likely sites and specific local physical features that might harbor life or otherwise be of very high interest and in deciding which sites should be sampled, and in ongoing evaluations of exploration conditions.

2. Planetary protection must be assured before any contact is made with Martian materials. Thus, PP controls must be addressed as a part of the initial stages of mission and hardware design for interplanetary missions, especially for, but not limited to, surface exploration missions including humans.

3. Because humans are hosts to a complex biological community related to digestion and many other human functions, all components of a human mission cannot be sterilized before launch and many PP issues and risks will arise with the addition of a human component to the mission.

4. The planning of human missions, including base site location and mission objectives, must be based on detailed local site information from precursor robotic evaluation and sample return missions.

5. At present, it is not easy to apply definitions of Earth life to possible Martian life. Life on Earth has been found in locations with temperature, physical, radiation, and/or chemical environments previously thought to be incompatible with life. Some Martian life (and other non-terrestrial life) potentially may also exist in forms and in locations we cannot now fully predict.

6. All operations of an initial human mission to Mars should include isolation of humans from any direct contact with materials from Mars for both PP and scientific purposes.

7. Further definition is needed for a system describing and categorizing Martian sites of special scientific interest and of level of contamination concern. These classification systems should be developed and employed in future PP protocols as well as in operational plans for later human missions to Mars.

8. Further study must be given to long-term forward PP concerns and the possible interaction of any forward contaminants with surface features and disturbances on Mars, given that it will be difficult to guarantee all human life processes and mission operations are

conducted within entirely closed systems. Such information may be key to understanding the risks involved and the level of closure needed for these systems. There may be critical emerging issues regarding possible ecological developments on Mars associated with how Earth organisms can act and possibly evolve in the presence of Martian materials.

9. General human factors need to be considered along with PP issues for a human mission to Mars. Physical effects which lead to debilitation and reduced performance capability in astronauts may lead to unintended actions or behaviors which could in turn lead to mishaps with potentially serious planetary protection consequences. Mistakes are much more likely when people are tired, ill, and/or overstressed.

10. Additional development and design attention will be needed for many exploration, sampling, and base activities to assure both effective operation and the required level of PP assurance. Based on current and anticipated technologies, subsurface sampling operations appear particularly problematic for use on Mars with respect to PP issues.

NEEDED AREAS OF RESEARCH

The conclusions and general recommendations raise many questions where a better knowledge base is needed prior to a human mission to Mars. Among the many areas of needed research, the following were specifically noted as major needs at the Workshop:

1. Define the spatial dispersion of dust and contaminants on Mars by wind and other means.

2. Describe the potential impacts of each of the many human support activities expected in the operation of a human-occupied Martian base, e.g. breathing oxygen, food supply, waste management, etc.

3. Determine how robotics can best help conduct operations on Mars in a way consistent with PP concerns, both independently during precursor missions and in conjunction with humans in later missions.

4. Improve space suit designs consistent with PP needs, especially for the demands of human activities on the Martian surface located away from pressurized habitats and rovers.

5. Develop technology required for life detection and potential pathogen detection (e.g. DNA/RNA) with a focus on sensitivity and specificity of tests as needed to answer “how clean is clean enough?” and “how ‘alive’ is indeed alive?”.

6. Formulate a site classification system and biological plausibility maps of the martian surface and subsurface based on remote sensing data and prior returned sample analyses. Particular maps that were suggested included those of special scientific interest, levels of contamination concern, and human mission operations zoning.

RECOMMENDATIONS FOR FUTURE WORKSHOP TOPICS

Given the exploratory and general nature of the Workshop, it is not surprising that a myriad of potential future workshop suggestions arose. Improved information and planning in many areas will be needed before the formulation of specific mission protocols. Specific attention was given to possible future topics on quite broad issues rather than specific tasks and mission operations, with the following potential workshops noted:

1. “If Life, Then What” which would address appropriate responses to the discovery of Martian life, whether in a robotic mission sample return or during the first or later human mission to Mars.

2. General human health issues, life support, work environment, psychological, and other human factors, along with their interaction with PP issues and general performance within extended mission of several to many months.

3. Communications with the public, via two separate workshops, one on the general public response to the detection of extraterrestrial life on Mars (or elsewhere away from Earth), and the other on planning to prepare the public for the possible discovery of non-terrestrial life.

WORKGROUP SUMMARIES

The summaries below provide additional detail on some of the scientific, technical and research challenges ahead, with special emphasis on those having significant engineering and technical implications. Complete documentation of the specific deliberations, findings and recommendations of the entire workshop may be found in the final report (Criswell et al., 2003).

WORKGOUP I: “PROTECTING MARS AND SCIENCE”

Protecting Mars during human missions involves consideration of many parameters, including how we design and prepare a mission, what is known from precursor missions, what is brought to Mars, where the landing is to be, and what are the planned activities during the exploration. A key parameter is how conducive the conditions at a specific site may be for both the support of Martian life and for any introduced organisms of Earth origin. Workgroup discussions first emphasized the identification and understanding of these spatial areas of high biological interest, followed by considerations of the classes and origins of possible contaminants, their possible behavior and impact in the Martian environment, and aspects of mission operations. In general, more and better information from precursor robotic missions will allow a most efficient, productive human mission to follow.

The group advocated a rigorous but flexible set of guidelines pertaining to forward contamination controls and chemical contamination limits. Guidelines should be updated prior to human missions to reflect new detection and cleaning methodologies as well as advances in knowledge about Mars. Such guidelines are likely to evolve considerably from precursor missions, to early human exploration, and on through advanced human missions.

The group also analyzed two human mission scenarios—one near term in 2020, the other long term in 2050—and considered the differences in PP issues expected. These exercises helped identify key research questions and directions for the coming years.

For an early human mission, prior precursor missions will presumably contribute much needed information about Mars. Even with this information, strict controls will likely be required for operations, human activities and areas, science experiments and mobility systems—all of which will need considerable R&D. It is also likely that a uniform containment strategy will be required for all science sites until sufficient additional information will allow relaxation of containment restrictions. Long term missions may be operationally easier due to anticipated technological advances from earlier missions, both robotic and human.

Specific research questions that were identified include:

- Detailed information and environmental characteristics for landing vicinity in order to specify landing site and operations area, habitat location, exploratory zones, and important subsurface features

- Development of space suits for human activities in ambient martian conditions

- Modification or redesign of current suit venting systems applicable to Mars situations

- Determination of levels of filtration that are possible or needed for suits, living or work modules, rovers, etc.

- Information on release/escape of microbes from suits and development of detection and monitoring procedures

- Life support systems (including waste containment and preparation for final departure from Mars)

- Determination of how clean the items used on the martian surface must be (e.g., mobility elements, tools, sampling devices etc.) and how these high level design requirements can be defined

- Determination of what levels of chemical cleanliness or sterility will be required and how can they be monitored? What methods can be used to clean or sterilize materials on Mars in the human mission context?

- Will the different possible microbial communities, if mixed, become one homogenized community over time, or remain separate? How can this be monitored? What are the implications for Mars, as well as for future human missions and exploration?

- What are the likely broad non-biological ‘ecological’ impacts on Mars (e.g., excavation, construction, etc.)? What mitigation plans could be developed, if any?

For the near term human mission (circa 2020) research most pertinent to PP issues includes:

- Contamination control technology and procedures consistent with, but not limited to, current PP requirements

- Spacecraft cleanliness and isolation of other sources of contamination (humans, life support, etc.)

- Contamination control from non-biological sources during human missions (e.g., mechanical disturbances, rover, exhaust, airborne pollution, water, heat, light, etc.)

- Carbon elimination techniques

- Use of ethylene dioxide and other gases for sterilization

- Levels of biological and chemical residues expected/acceptable on various equipment, surfaces and materials?

- Monitoring/measurement techniques/procedures for environmental contamination as well as for astronaut physiology

Research most pertinent to PP issues on long term missions (circa 2050) focused mainly on contamination:

Prior to Departure:

- Inventory of possible contaminating microbial threats/communities that might be carried by a human mission (what kinds, where possibly located, and what levels?)

On Mars:

- Probability of microbes making contact with Mars

- Viability, growth, mutations, dispersion and propagation (local vs. global)

- Impact on Mars sterility and/or indigenous biota

- Impact on life detection experiments

- Comparative research on cave contamination, a good terrestrial analogue

- Detection of indigenous biota by unmasking/activating dormant indigenous biota

Workgroup 1 also proposed an evaluation scheme and matrix integrating specific measures and items that relate to PP goals. The group suggested that an n-dimensional structuring and analysis of the various items could yield helpful information on relative degrees of difficulty and sensitivity of different missions. In essence, by using overlapping sets of classifications and concerns, individual mission scenarios can be assessed and PP needs predicted. While details of the matrix and analytical approaches will need considerable future development, the approach may yield useful insights into PP impacts by focusing on the following important categories of concern:

a) *Classification of sites of special scientific or biological interest*: A classification system was proposed using Classes I-V based on increasing probability of long term existence of liquid water and a progressive development towards more Earth-like conditions. Class I-III represent sites with no or only limited biological interest because of the low probability of survival of living materials; Class IV and V represent sites of high and intense biological interest respectively, because survival of life is considered either possible or highly probable.

b) *Identification of contaminating microbial communities*: For human missions it will be important to identify, characterize and monitor for distinctive contamination sources and microbial communities whose ecological contexts and physiological properties are sufficiently different to warrant separate assessments. Important communities by origin include spacecraft, robots, humans, life support systems, and other potential sources. In addition to assessing locations within the mission and their microbial characteristics, it will be important to assess the microbes' abilities to survive the journey to Mars and cause possible impacts of importance to Mars, humans, or scientific experiments.

c) Zones of contamination control: Two modes of contamination zoning were considered for habitat and operational areas on Mars. Areas close in to the habitat would be considered zones of higher potential contamination, while distant, more sensitive or less explored destinations would be declared "full procedure zones" requiring maximum procedural controls and decontamination until more is known about the area.

d) *Temporal and sequencing issues*: Consideration should be given to the sequencing of operations on Mars as well as contamination monitoring, decontamination and associated procedures. Details will be mission dependent.

e) *Human operations*: In the matrix, critical decisions regarding the exact mix of human, robotic and human-guided robotic sorties will have to be addressed for their differing PP implications.

WORKGROUP II: " PROTECTING HUMAN HEALTH"

Workgroup II considered hazards and consequences to human health from anticipated and unanticipated risks, and control of exposure to risks during habitat occupancy and exploration operations. Early in the discussions, the group chose to ignore factors not specific to planetary protection (i.e., microgravity, low atmospheric pressure, atmospheric gas composition, etc.) and selectively concentrated on factors such as ionizing radiation, dust and electrical discharge, dust composition, dust toxicity, and questions related to possible Martian life forms. Discussions centered around topics of concern for each of these factors. Primary topics were organized into a matrix including the six risk factors:

1. Physical and health status of astronauts throughout the long-duration Mars mission

2. Human behavior and performance

3. Physical interaction with the Mars environment, including dust, chemical, mechanical, electrical discharge, and radiation (cosmic, n-backscatter, indigenous)

4. Biohazards

5. Clinical concerns such as injury and disease, and

6. Protection of Mars from effects of human activity on Mars such as physical wastes, human wastes and life support system effluents.

Points of special concern included:

A possible hazard with martian dust is that of immune suppression. Dust may result in decreased human resistance to radiation damage, especially with deeper lung penetration of very small particles (diameter 1-3 microns). During mission operations, it will be impossible to keep dust out of everything. Even if astronauts stay inside a 'submersible-type' habitat, dust will be brought inside by routine operations and use of equipment. The dusty regolith on the surface of Mars is likely to be reactive raising numerous concerns. What are the necessary limits on dust exposure? What are the implications of mixing martian dust and water? Could superoxides brought into the laboratory environment produce reactive, damaging products when introduced to water, including water vapor within the habitat breathing atmosphere? Could organics be broken down? Other questions focus on external concerns. For example, what microenvironment(s) would be created by virtue of human presence on the planet? (ex., from vented gases, wastes, etc.) If an outside surface area is contaminated locally, how rapidly will the contamination spread? Will there be thermal decay? What problems could be caused by desiccation or UV radiation? How much will be blown around by dust storms? These unknowns raise other health related questions about dusts: How much can humans be exposed to the Mars environment, if at all? In the base operation, will it be possible to seal or otherwise isolate the human occupancy areas from other areas, such as less secure laboratories? Will crew be allowed to enter and work in less secure areas without taking extra precautions? Will robotics technology be sufficiently advanced to deal with repair and maintenance needs in less secure areas? What would happen if humans are contaminated in some way?

There is need to be concerned about the prospect of Mars samples or materials contaminating humans. In looking for life on Mars, astronauts will be drilling in places likely to find life. Operations that involve digging beneath the surface of Mars may produce biohazards. Special care must be taken when looking for biological evidence of previous or extant life in subsurface locations. Appropriate technology must be developed to deal with diverse potential biohazards, however unlikely —perhaps reviving relic life, or finding life forms similar to bacteria or viruses. Care must be take to ensure that no uncontained materials are brought back that could be infectious or otherwise harmful. A protocol for handling and testing of potentially biohazardous materials must be developed for use under martian conditions, with appropriate technology for handling, quarantining, and testing samples, and sterilizing, and curating materials as needed. Monitoring and verification of systems will likewise be required. It is also widely recognized that there will be a need to fully characterize the site(s) where humans might go. Yet questions remain about how full is 'fully'? and can it be done remotely? Geologists will need to identify, prioritize and put findings into context in order to help decide where to drill when subsurface exploration is planned. Depending on the quality of sample required or how fast the results are needed, perhaps robots can do much or most of this work.

Other health concerns may not be directly related to Mars biohazards and toxicity issues. For example, the microbes that accompany the explorers to Mars may cause sickness while on the planet or en route. The presence of pathogenic microbes in sick astronauts would presumably raise more containment issues. Sickness could also impair the alertness and productivity of astronauts, with implications for operational difficulties or breaches of protocols. Human dependencies on trace elements may arise unless dietary planning pays specific attention to their needs. Injuries from operations or accidents in and around the base area or on rover excursions may be problematic in numerous ways, and must be considered in mission planning.

Life support will clearly need far more attention than it has received to date. While closed loop systems are preferred for planetary protection, it is unclear how this will be done technologically? Can a habitat be deployed or built robotically on the surface and its operational readiness be fully verified prior to sending humans there? Does venting of habitat products create problems or raise contamination issues? In preparing for the return of crew to Earth, should wastes be left behind, and if so, where and under what conditions? Will space suits be sealed completely? Will rovers or the habitat likewise require complete sealing? The synergies and interactions between the different mission elements—the people, rover, sampling and habitats—will need careful and extensive analysis in order to embark on a focused R&D program aimed at creating life support conditions conducive for overall mission success, including meeting PP requirements.

WORKGROUP III: "PROTECTING EARTH"

Workgroup III addressed the linkages between sampling, handling and return preparations for both crew and samples on Mars as well as procedures upon mission return to Earth. Since it may be impossible in the near term to know with certainty whether life exists on Mars, it is important to take a conservative approach to PP controls for human missions. This is similar to the approach for robotic sample return missions based on recommendations by the Space Studies Board (SSB, 1997) that all materials returned to Earth from Mars must be contained and considered as possible biohazards until proven otherwise. The workgroup recommended that until it is certain there is no life on Mars (initial missions), all missions with human crews must maintain this same conservative approach. This translates inrto careful planning of activities and equipment in transit, on Mars, and back on Earth, and will mean containment for samples, spacecraft parts and equipment that have been exposed to the Martian surface, as well as containment or isolation for returning astronauts. Obviously, if life is discovered on Mars prior to the first human mission, it would require a complete reassessment of all designs, protocols and operations in light of this new information.

Containment and contamination avoidance

In concentrating on back contamination issues for human missions, Workgroup 3 advocated avoidance of back contamination of the Earth by focusing on both returned sample materials and crewmembers separately and in combination.

Back Contamination and Returned Samples: In general, back contamination of Earth can be avoided by containing returned samples or materials exposed to the martian environment and by breaking the chain of contact with Mars in an appropriate manner. Alternatively, back contamination can also be avoided by sterilizing pristine martian materials on Earth prior to release from containment (methods to be determined). For human missions in particular, prevention of back contamination is also based on the ability to isolate samples, some of which might contain replicating biohazards, from the crew and their habitat.

Isolation of samples must begin when samples are being collected and handled, continue through any testing or handling on Mars, and be maintained throughout the return flight and transit to containment facilities on Earth. The workgroup advocated using the recently developed Draft Protocol (or its future refinements) for guiding the handling and testing of martian samples during human missions (Rummel et al., 2002; Race and Rummel, ICES 2003). Appropriate containment (biosafety and cleanliness conditions) of collected samples should be maintained in transit as well as during any sample screening or preliminary science analyses in situ, in field labs, or in the lab at the base camp. Moreover, the base camp lab should be completely separate from the crew habitation quarters, and methods should be devised to introduce the contained samples into the lab through entry ports dedicated for samples only.

Back Contamination and Crewmembers: For both robotic and human missions, the operative concern about back contamination is that of exposure per se. For human missions, if methods can be devised to prevent exposure of the crew to uncontained martian materials or habitats, then concerns about human-associated back contamination can be reduced substantially, if not eliminated. Using this rationale, if humans are kept successfully isolated from biohazards, they acquire no exposure to biohazards, thus reducing the need for any special isolation or monitoring beyond that required for medical observation upon return to Earth.

The workgroup recommended isolating crew from the martian environment at all times to eliminate the major concerns about exposure (rather than devising elaborate protocols for assessing the crew for biohazards upon return). It will be important to maintain isolation from Martian materials during scientific exploration as well as routine outside activities at the base camp (infrastructure maintenance, greenhouse activities, repair of equipment, etc.).[1] This 'non-exposure' approach is consistent with that routinely used in the biomedical community when dealing with known virulent and pathogenic organisms or biohazardous materials. Biohazard monitoring— details of which are yet to be determined (TBD) -- could be included in conjunction with the extensive medical testing that will be a part of any human mission. The lengthy return flight virtually imposes a quarantine of suitable duration to detect obvious health impacts that might pose back contamination concerns.

To accommodate the possibility of a breach in containment, lapse in protocols or presumed inadvertent exposure, the mission architecture must be able to accommodate containment of the crew, spacecraft and equipment until they arrive at a containment facility on Earth. Depending on mission architecture, isolation of crew and vehicle during transfer in Low Earth Orbit may be required. Upon return to Earth, continued monitoring can occur during the anticipated post-flight medical isolation to ensure that no indications of exposure or biohazards are detected. Decisions about release of crew or continuation of medical isolation would be made upon review of medical information on Earth.

Concept of Zoning for Human Mission Operations

During human missions, collection of martian materials from a variety of locations will be undertaken. Some sites will be of great biological interest, constituting concern about potential biological contamination; other sites or zones are likely to contain materials of no biological interest or associated contamination concerns. To address these differences, the group developed a zoning concept based on an iterative, incremental definition of operations zones on Mars designated by two considerations: 1) the extent to which a site or zone is scientifically characterized and 2) its level of biological potential or interest. Under this scheme, the following areas or zones were proposed:

Inside Environments:
1. Habitable zone: Areas within structures, vehicles, suits etc. capable of supporting human life.

Outside Environments:
2. Characterized sites or zones— previously studied and characterized sufficient to determine whether it:
   a. is 'safe' from microbial biohazards and may be 'pre-cleared' for extensive human operations and activities or
   b. warrants some limitations on human access and operations by virtue of its biological potential

3. Uncharacterized sites—zones or areas with insufficient data to make a determination about the level of biological potential or interest. Operations at these sites warrant limitations on human access or operations until they can be characterized more fully.

The designation of these four categories (habitable; characterized/safe; characterized/limited access; or uncharacterized) may also be used in combination with the site classification scheme devised by Workgroup 1 for forward contamination concerns [Classes I-V, ranging from no biological interest to intense biological interest).

Designation of 'Safe' Operational Zones

Using the proposed categorization, zones that are well characterized and are determined to have no indication of biological potential, are designated as "safe zones,"

[1] Martian materials used for agricultural purposes, especially for growing food for human consumption, must be sterilized or otherwise treated to maintain isolation from potential martian biohazard.

cleared for , because they are devoid of Martian life. In designated safe zones both sampling and routine activities may be conducted without robot or remote intervention. Even in designated safe areas it will be important to maintain the isolation between crew and Martian materials. Presumably, the immediate area of the landing site and base camp would be located in a previously characterized area that is of no biological interest and thereby 'pre-cleared' for human activity. This determination is dependent upon an iterative process using data from precursor missions, previously returned martian samples, as well asterials down atmospheric and surface transport models for two objectives:

1. Definition of what Mars surface material can be considered globally identical

2. Determination that this material comprises the first safe zone.

The workgroup noted that analysis of data from precursor missions and returned samples will be essential to show that wind deposited dusts and surface materials of general geological origin down to some depth are safe from microbial biohazard—and may be cleared initially as suitable zones for landing sites and establishment of base camp infrastructure. In addition, since dispersal of dusts will be inevitable during martian missions, it will be important to verify that these materials do not constitute a biohazard for operational purposes. Assuming that wind-blown dusts will not be found to be a biohazard, this zone categorization process would enable planetary protection tolerance of small, manageable amounts of dust inside habitable facilities. Tolerating dust in this manner in turn permits practical operations on long-duration human surface missions.

This operation approach concerning dusts leads to two primary operational requirements:

1. Ingress/egress systems that limit the total amount of dust getting inside the habitable zone, and procedures that control and clean away the dust that does get inside. These technologies, then, are not driven by the replicating biohazard back contamination risk, but rather by other engineering and toxicity requirements.

2. A process of managing the boundary between the safe/cleared zone and zones which may still pose back-contamination hazard or remain uncharacterized. The long-term objective is, through incremental investigation, to shift the boundary so that the safe/cleared zone expands, perhaps ultimately to comprise all of Mars.

The categorization process should be used incrementally to declare other zones or areas as bio-safe for humans. Crews should be sent only to sites deemed bio-safe by previous analyses and characterization. In uncharacterized areas or areas determined to present potential biological concern, initial sampling or reconnaissance should be done robotically or remotely in order to determine whether and how future human activities may be safely permitted in the area.

The bounding parameters of sites or zones with biological potential may be designated in a variety of ways—either as a location per se (e.g. a brine seep) or a combination of important geometrical (latitude, longitude, depth), geological (material composition and mechanical properties) and/or environmental (hydration, temperature) features. The boundary so defined may vary diurnally, seasonally or secularly as operations proceed. Exploration and sample retrieval within the bounds of zones with biological potential must be done in a manner that maintains the strict separation of the habitable zone for humans from the Mars material. This means that at no time may the materials from a non-cleared site be handled in such a way that they contaminate surfaces that will be introduced into the habitable zone. There remain numerous challenging questions on how to clean rover vehicles, tools, astronaut suits, etc., as the boundary between non-cleared and cleared areas is crossed.

In summary, the overall constraints required to enforce isolation of potential martian biohazards and thereby protect Earth from potentially harmful cross contamination include:

1. Acquisition of samples must be accomplished in a manner that isolates samples from crew and habitat.

2. All sample handling, screening, analysis and transport must be done under containment.

3. Samples collected during human missions must be handled and taken to an Earth Planetary Protection Level-α facility (as defined in Draft Protocol, Rummel et al., 2002), just as samples in robotic missions are returned.

4. The crew will undergo follow-up medical isolation coincident with astronaut health analyses and requirements.

Additional contingency constraints imposed due to inadvertent exposure (breach of isolation) include:

5. Containment of astronauts, spacecraft and samples at appropriate biosafety levels or PPL's[2] is required from re-entry through arrival at appropriate terrestrial facilities.

6. Exterior of re-entry vehicle must break the chain of contact with the Martian biosphere.

[2] BSL= Biosafety levels as defined in CDC-NIH (1999), and Planetary Protection Levels (BSL *plus* stringent cleanliness conditions needed to ensure the scientific integrity of pristine martian samples) as described in Rummel et al, 2002.

7. Clearance and release of crew to be determined based on analysis of samples and medical testing.

The following technology and science areas were identified as important for preventing back contamination of Earth by biologically-active agents. Research and development will be needed on:

1. A suite of technologies for use on Mars either *in situ*, in the base camp laboratory or in a mobile facility, all to facilitate analysis of uncharacterized areas of Mars with the potential for supporting life.

2. Appropriate technology to limit exposure of the crew and habitat module to the Mars environment, such as

   a. Make improvements in systems for robotic sampling at sites with the potential for life that integrate human control and decision making into the design,
   b. Design or modify tools to be used by humans that will allow sample retrieval and minimize the risk of exposure,
   c. Design or modify sample transport containers, transfer ports, examination boxes, and laboratory space (with air cleaning/filtering) that prevent exposure of the crew and habitat to sample materials, but allow necessary scientific study of samples,
   d. Develop or refine suit technology that limits contamination of the crew habitat (exo-suits/rovers? Suitlocks?), but that can be easily cleaned and maintained.

3. Precursor data to establish that the Martian dust is global in nature and is not a biohazard.

4. Studies of the psychological stress of long-term missions on crew performance including evaluation of the potential problems and solutions associated with human behavior and operations. Maintaining a barrier between the Martian environment and the crew will depend on strict compliance with isolation and operational protocols. In developing the protocols, it will be important to consider the possibility that the crew might intentionally violate the protocol, thereby creating potential PP problems.

“OPERATIONS” WORKGROUPS

The two workgroups on “Enabling a Safe Productive Human Presence in the Exploration of Mars” explored operation issues including general habitat design features, support and exploration equipment, and base operation procedures consistent with forward and back contamination control. The groups each examined six scenarios for issues of back and forward contamination:

1. Distant surface sample collection
2. Sample analysis
3. *In Situ* Resource Utilization (ISRU) at the base
4. Plant growth experiments and greenhouses
5. Sub-surface sampling (10 m vs. 1 km)
6. Implications of finding life

A combination of major identified areas of operational importance is presented briefly below. This overview provides a sense of the systems, operations, and considerations that will be critical for eventual mission success. For more detailed discussion, refer to the workshop report (Criswell et al., 2003).

Issue 1. Distant Surface Sample Collection

All equipment and basically everything used in sample collection and handling should “cleanable” *in-situ* to TBD specifications, with special attention on avoiding cross contamination. Attention will also be needed on repair and maintenance of sampling equipment in situ.

Routes and paths to sites of interest need to be pre-designated to minimize adverse impacts (e.g. mechanical disturbance) and maintain integrity of sites both in areas of high biological interest and the regions that are traversed en route to various sites.

Remote assessment of sites using advanced robotic reconnaissance (via telerobotic, semi-autonomous, and autonomous scouts) will be needed prior to sending humans.

New technology is needed to minimize forward contamination from suit leaks or venting and from various equipment (robots, pressurized rovers, etc.) and operational procedures. Research is needed on suit contamination containment technologies, including monitoring, cleaning and decontamination methods and procedures for managing forward and back contamination control when humans venture into locations where robots cannot be sent.

Issue 2. Sample Analysis

An overall guideline should be to assume life is in the sample until proven otherwise. All protocols should be based on this guideline.

Containment redundancies are necessary during sample handling, preparation and analysis.

Samples should be kept as isolated as possible at first, and as appropriate as more is learned. Spill containment and cleanup policies and procedures should be well defined, tested, and in place well before the first transfer of martian samples to the base or areas in contact with humans.

Issue 3. ISRU at Base

ISRU likely will present the need to deal with contamination issues for large volumes of materials.

ISRU operations should be conducted so they do not affect regional or planetary ecology beyond the ISRU zone.

Equipment and processes for ISRU must minimize an undesirable introduction of hazardous materials or byproducts into the planetary environment (e.g., must filter vent gases).

Contaminant and dust dispersion paths and mechanisms must be understood before large-scale ISRU operations are undertaken. Including ISRU on the first human mission may not be advisable. This should not preclude ISRU demonstrations on precursor robotic missions to collect information for the purpose of enablihg future human missions.

A non-invasive biological assessment of ground ice should be done prior to the use of this ice for any reason. Extraction processes should also be non-invasive. Lake Vostok is a possible terrestrial analog for exploring such non-invasive processes, especially in preparing for drilling through ice into potential aquifers. Because any given source of water will not likely be well understood, mission operations should not depend on in-situ water sources, at least in the beginning, until those sources are extremely well understood.

As a related side-note, infrastructure construction, operations, and maintenance are all potential sources of environmental disturbance that need to addressed and preferably minimized.

Issue 4. Plant Growth Experiments and Greenhouses

If martian materials are used with greenhouses, concerns similar to those for ISRU apply.

The contact of plants and associated organisms from Earth (either in experiments or inadvertent releases or leaks) with parts of the Mars environment could conceivably result in a third ecology (Mars plus Earth microbes?) with unpredictable properties. Dispersal effects associated with various experiments/missions should be studied in terms of the potential for spread into the immediate local environment, the wider local area, regionally, globally, and to sub-surface environments.

Special care should be taken in the release of any contaminants (possibly including gases?) from the greenhouses into the Mars environment as well as in development of procedures using martian soils etc. inside greenhouses.

The transition from scientific experiments using plants to the utilization of plants to grow food must be carefully managed and studied. The growth, harvesting, processing and consumption of food from greenhouses must be monitored to assure non-contaminated food products for the astronauts and compliance with appropriate PP controls.

Issue 5. Sampling

There is a need for new technology to effectively conduct drilling operations in remote sites under demanding physical and environmental conditions for both robotic sampling and human-aided sampling. New technologies should be developed to provide ways to minimize the potential for cross contamination of the surface site footprint and subsurface environments using robotic sampling approaches, particularly for subsurface pentration in the range of 10 meters.

Issue 6. What to do when life is found?

If life is found, the implications and responses are likely to be highly scenario dependent and there will be a need to follow pre-established procedures which must be developed well in advance. Some examples of the scenario dependence are: (1) subsurface vs. surface (including venting) vs. accessible subsurface, (2) extensiveness of the life-form – e.g. how much and how distributed? (3) temporal dependence – e.g. when in the mission cycle does the discovery occur?, (4) discovery of life in lab vs. outside the lab.

If life is found, it will be extremely important to avoid cross contamination, to maintain sample integrity for scientific reasons, and to emphasixe the use of non-invasive monitoring techniques during handling and study.

Although beyond the scope of this workshop, the workgroups also urged consideration of the broader societal issues and concerns associated with the discovery of martian life. The implementation of planetary protection controls during early human missions will set important precedents for subsequent exploration and colonization, and should reflect an appropriately broad combination of scientific and other concerns.

CONCLUSIONS

Although long-duration human interplanetary missions are not planned for the near future, it is important to begin considering the implications of human exploration from a planetary protection standpoint. A primary question is whether human missions can be accomplished in ways that avoid harmful cross contamination of planets as required by various international and domestic PP policies. Successful mission design will require consideration of how to protect Mars, the astronauts and the Earth throughout each mission. A preliminary, but comprehensive analysis at a recent NASA workshop indicates it is conceptually possible to develop systems, approaches and operational plans to enable safe, productive human missions for use in remote and hostile environments on Mars. Planetary protection issues will most definitely affect the design, operation and cost of advanced life support, environmental and scientific systems for long duration human missions. Critical design and operational considerations include human health and life support needs and equipment; laboratory and exploration equipment; mitigation procedures and equipment; site and regional planning; and back contamination controls and procedures for the return to Earth. The science and PP needs combined with the technical and engineering challenges ahead are significant enough to affect all phases of mission design, and ultimately success. Solving the challenges will depend on information from precursor robotic missions, research and development of new technologies, and close working relations between scientific, technical and engineering communities in the years ahead.

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